Effects of Polyacrylamide and Gypsum on Soil Erosion and Sediment Transport

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1. Abstract

This study evaluates the effectiveness of two popular soil amendments of gypsum and polyacrylamide (PAM) in minimizing soil erosion from one soil and one overburden (spoil) material of a mine rehabilitation site in Central Queensland. The treatments included an untreated soil (control), a gypsum application rate of 10 t/ha, an anionic PAM application rate of 40 kg/ha, and combined application of both amendments (PAM+gypsum) at the same rates as above, all replicated three times. Rainfall experiments were carried out in the Griffith University's rainfall-runoff simulation facility on 9% slope, at the mean rainfall intensity of 120 mm/h and the duration of 30 minutes. Runoff and sediment samples were collected at certain time intervals during the experiments.

Total soil loss from the treated soil and spoil were significantly lower than for control. Total soil loss for soil were reduced by 39%, 43%, and 74%, respectively for gypsum, PAM, and PAM+gypsum treatments, compared to the control. Furthermore, total soil loss for spoil were reduced by 41%, 50%, and 70%, respectively for gypsum, PAM, and PAM+gypsum treatments, compared to the control. Results indicate that the use of gypsum, PAM, and the combination of both significantly reduce total soil loss from the soil and spoil of the mine rehabilitation site but the combination of the two gives the best results for both soil and spoil.

The improved surface conditions on the treated soil and spoil contributed towards the reduction of sediment concentration in runoff and total soil loss. The soil amendments were effective in maintaining a well-aggregated soil surface that minimize detachment and was resistant to surface sealing. The application of soil amendments on the slopes prior to the establishment of vegetation may be an effective way of reducing erosion and minimizing the offsite consequences of sediment transport prior to the establishment of a viable vegetation cover. These amendments appear to increase soil moisture thus helping the establishment of the vegetation cover as well.

2. Introduction

Parts of the reconstructed landscape post open-cut mining operations always drain externally into and often directly connected with natural waterways. Surface runoff from these areas, often laden with a high sediment load, can have significant impacts on the surrounding environment. Although vegetative cover can minimize runoff and total soil loss, the period prior to the establishment of vegetation is crucial as the soil surface is in bare condition (Carroll et al., 2000). For this reason, the application of soil amendment such as gypsum and polyacrylamide (PAM) in this period can be beneficial in minimising runoff and soil loss.

The effectiveness of PAM application to reduce soil erosion has been widely studied by a number of researchers (Cochrane et al., 2005; Flanagan et al., 2003; Levin et al., 1991; Levy & Agassi, 1995; Peterson et al., 2002a; Zhang et al., 1998). One of the key effectiveness of PAM is its ability to preserve aggregate structure thus reducing surface sealing and promoting increased infiltration (Peterson et al., 2002b). Anionic PAM of high molecular weight (12–15 million g/mol) was found to be quite effective to stabilise soil structure, which leads to increased infiltration and reduced erosion. Although PAM has the ability to stabilise soil structure, it does not remediate poor soil structure (Cook & Nelson, 1986; Lentz & Sojka, 1994).

Gypsum is generally the amendment used most because of its availability and its low cost. Gypsum application to the soil has the ability to minimise clay dispersion which then improves the permeability of the soil and increase the stability aggregates at the soil surface. The electrolyte concentration and the replacement of exchangeable Na by Ca at the soil surface is the reason of gypsum effectiveness (Korcak, 2001; Shainberg et al., 1989). PAM and gypsum will be tested in this study to determine their effectiveness in minimising sediment concentration in runoff and total soil loss.

3. Methods

Griffith University Tilting Flume Simulated Rainfall (GUTSR) facility was used for all of the soil erosion experiments conducted in this study. The flume bed specification for all of the spoil and soil experiments in this study is 5.8 m in length and 0.5 m in width and the depth of the soil is 0.1 m. The slope of 9% and rainfall rate of 120 mm/hr were used for the entire soil erosion experiments in this study.

One soil and one overburden (spoil) material of a mine rehabilitation site in Central Queensland were used in this study. The soil and spoil samples were air-dried and the gravel >50 mm in diameter removed before

it was used for the experiments. The required amounts of samples were placed on the flume bed and were spread along the length and width of the flume to obtain a uniform depth of 0.1 m with a flat surface.

Two types of soil amendments, namely gypsum and PAM, were used in this study. Gypsum used for this study was from Richgro Garden Products. The PAM used for this study is Superfloc A-110 dry polymer from Cytec Industries. The polymer has low anionic charge and high molecular weight (>10 million g/mol). Gypsum is applied by hand at the required rate and mixed with the upper 5 cm of the soil and spoil samples for the gypsum treated experiments. For PAM treated experiments, the granular PAM was applied by hand at the soil and spoil surfaces. As for the combination of PAM+gypsum experiment, gypsum was applied by hand at the required rate and mixed with the upper 5 cm of the samples and then PAM is applied at the surface. The samples were then pre-wetted 24 hour at 0% slope prior to the commencement of the experiments. Table 3.1 shows the overall experiment conducted in this study.

Table 3.1 List of proposed treatments and associated application rates

Material	Treatment	Application rate (kg/ha)		Replicate
		PAM	Gypsum	
Soil	Control			3
	PAM	40		3
	Gypsum		10000	3
	PAM + gypsum	40	10000	3
Spoil	Control			3
	PAM	40		3
	Gypsum		10000	3
	PAM + gypsum	40	10000	3

4. Results

The majority of the results indicated that the sediment concentration was generally highest in the early stage of the experiment (first 5 minutes) and decreased with time until it reached steady stage condition which are shown in Figures 4.1 and 4.2. The increase of sediment concentration in the first 5 minutes for control treatment is mainly because of the elevated occurrence of fine particles in the eroded sediment. These fine particles are generated from the breakdown of aggregates from soil wetting before the experiment commence and rainfall impact during the experiment. Furthermore, the decrease of sediment concentration with time in soil control could have been caused by the development of deposited layer that was formed by the size-selective process of deposition. The increasing amount of deposited layer generally consists of coarse sediments.

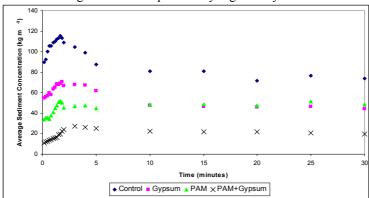


Figure 4.1 Comparison of the average sediment concentration with time for soil under various treatments

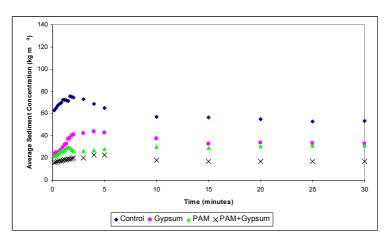


Figure 4.2 Comparison of the average sediment concentration with time for spoil under various treatments

The application of amendments to the soil and spoil was found to be beneficial in minimising sediment concentration in runoff. Gypsum treatment was effective in maintaining a well-aggregated soil surface that minimises breakdown of aggregates by rainfall and runoff. When the gypsum concentration in the soil solution is sufficiently high, the tendency for clay to disperse is low thus soil aggregates remained intact. Gypsum application can maintain the roughness of the soil surface and also increases electrolyte concentration in both the runoff and the percolating water. Increasing the electrolyte concentration also prevents aggregate dispersion and bigger particles are less erodible (Shainberg et al., 1989).

PAM application to the soil and spoil results in lower sediment concentration when compared to the control experiments. The large molecules in anionic PAM bonded to the clay particles through cationic bridging, and possibly penetrated coarse-textured aggregates to bind them together, thus reducing aggregate breakdown (Cochrane et al., 2005). The saturated PAM may act as a shield to stabilise soil to some degree during the rainfall events thus reducing total soil loss. Another possibility is that the soil surface was sealed at the same time as the PAM became activated that minimise water infiltration, however, at the same time PAM strengthen the soil surface thus reducing soil detachment. Furthermore, PAM+gypsum resulted in additional benefits in further reducing sediment concentration when compared to gypsum and PAM application alone.

Table 4.1 Average total soil loss for soil

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Experiment	Average total	Total soil loss decrease		
	soil loss (kg)	from control (%)		
Control	13.24			
Gypsum	8.03	39		
PAM	7.6	43		
PAM+Gypsum	3.48	74		

Table 4.2 Average total soil loss for spoil

Experiment	Average total	Total soil loss decrease
	soil loss (kg)	from control (%)
Control	9.57	
Gypsum	5.68	41
PAM	4.74	50
PAM+Gypsum	2.88	70

Reduction of total soil loss due to the addition of soil amendments can be attributed to the decrease in soil erodibility or reduction of shearing action by flowing water (Peterson et al., 2002a). The results indicated that the erodibility was decreased in the gypsum, PAM, and PAM+gypsum treatments when compared to control. The applications of gypsum, PAM and PAM+gypsum were highly effective in considerably reducing total soil loss throughout all of the experiments which are shown in Tables 4.1 and 4.2. Soil loss reductions were achieved by the individual mechanisms under which each amendment works. Reduced soil loss in the gypsum, PAM and PAM + gypsum was attributed to the improved surface condition on these plots. The soil amendments were effective in maintaining a well-aggregated soil surface that was more resistant to soil erosion when compared to control. Whereas the untreated soil aggregates may disintegrate quickly and dispersed particles may

accumulate in the surface runoff that results in the high sediment concentration for control. This was evident from the high soil loss in the control experiments for the soil and spoil, which was initiated by rainfall impact energy causing surface aggregate to break down resulting in a large quantity of easily transported sediment particles coming into suspension.

Observations of the soil surface during the experiments indicated that sediment transport in the control experiments was dominated by rill flow. Rills that were formed in the experiments began as small channels on the soil surface. As the experiment progressed, the runoff that was concentrated in these small channels causing them to widened and deepened. However, soil amendment applications were beneficial in minimising rills from occurring throughout the experiments. Because rills development is usually associated with the increase of sediment concentration, this may account to the substantially high sediment concentration generated from the control compared to the gypsum, PAM, and PAM+gypsum treated experiments.

In conclusion, the improved surface conditions on the treated soil and spoil contributed towards the reduction of sediment concentration in runoff and total soil loss. The soil amendments were effective in maintaining a well-aggregated soil surface that minimize detachment and was resistant to surface sealing. The application of soil amendments on the slopes prior to the establishment of vegetation may be an effective way of reducing erosion and minimizing the offsite consequences of sediment transport prior to the establishment of a viable vegetation cover. These amendments appear to increase soil moisture thus helping the establishment of the vegetation cover as well.

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